

Population status of the Bornean orang-utan (*Pongo pygmaeus*) in the Sebangau peat swamp forest, Central Kalimantan, Indonesia

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Abstract

A survey of the density and population size of Bornean orang-utan (*Pongo pygmaeus*) was carried out in 1995 and 1996 in an area of peat swamp forest in the Sungai (River) Sebangau catchment, Central Kalimantan, Indonesia. Densities were calculated for four forest sub-types by counts of orang-utan sleeping platforms (nests) along line transects. Densities were found to be highest in the tall interior and mixed swamp forest sub-types. Low pole forest supported the lowest density. Habitat disturbance caused by logging was shown to affect orang-utan density within mixed swamp forest. The orang-utan population for a larger peat covered landscape unit (9200 km²), including the Sebangau catchment, was estimated to be between 5671 (± 955) and 8951 (± 1509) individuals, based upon the area of each forest type, the level of disturbance in each area and corrected to prevent overestimates. This study identifies the presence of a very large, self-sustaining orang-utan population in this region and emphasises the urgent requirement for greater protection of Kalimantan's peat swamp forests in the light of recent and rapid habitat degradation.

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1. Introduction

The orang-utan (*Pongo* spp.) was once widespread in Asia but is now found only on the islands of Borneo and Sumatra where it exists as two distinct species (*Pongo pygmaeus* and *Pongo abelii*), re-classified from two sub-species in 1999 (Groves, 1999). The Bornean orang-utan (*Pongo pygmaeus*) is believed to occur as three sub-species, *P. p. pygmaeus*, *P. p. wurmbii* and *P. p. morio* (Groves, 1999), although Warren et al. (2001) suggest four sub-populations that may or may not be distinct enough to be classified as sub-species. Whatever the case, current knowledge about the distribution, population size and conservation status of all sub-species/sub-populations is incomplete. In 1995, the population of the Bornean orang-utan was estimated to be between 10,200 and 15,500 individuals (Rijksen et al., 1995). The uncertainty surrounding these estimates

arises from an incomplete knowledge of species distribution, combined with evidence that suggests population numbers are undergoing continuous decline (Soemarna et al., 1995; Rijksen and Meijaard, 1999).

The orang-utan is known to inhabit primary and secondary forest and is typically found in lowland dipterocarp, freshwater and peat swamp forests. It has also been recorded in hill forests up to about 1500 m although at much lower densities than in other habitats (MacKinnon, 1974; Rijksen, 1978; Payne, 1988; Payne and Andau, 1989; Rijksen and Meijaard, 1999). All of these habitats are reducing in extent as a result of degradation and loss, principally from timber extraction (legal and illegal), forest fires and forest clearance for agriculture and settlement (Wilson and Wilson, 1975; EIA, 1998; Rijksen and Meijaard, 1999; Yeager, 1999). Reduction in habitat area, hunting of orang-utan for bushmeat and the capture of young animals for the pet trade, have greatly increased the vulnerability of the Bornean orang-utan in recent decades leading to its classification as an endangered species by the World Conservation Union (IUCN, 2000). It is also included

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in Appendix 1 (endangered species, trade in which is normally prohibited) of the Convention on the International Trade in Endangered Species (CITES). Even without widespread habitat destruction, orang-utan populations are naturally vulnerable owing to a low reproductive rate resulting from the long time taken to reach sexual maturity (up to 12 years) and a long inter-birth interval (typically 8 years; Galdikas and Wood, 1990; Rijksen and Meijaard, 1999).

Long-term conservation strategies for this great ape are urgently required but vital prerequisites to these are accurate baseline data on the density of the population across all habitats, the exact area and distribution of each habitat type, and the scale and impact of human intervention. Knowledge of the distribution of the Bornean orang-utan is especially incomplete, with many unprotected areas of Kalimantan (Indonesian Borneo) remaining unsurveyed (Rijksen et al., 1995). One recent study, based largely on secondary information derived from environmental impact assessment statements and questionnaires to logging concessionaires, has provided the most up to date overview of the present distribution of this species and has highlighted the contemporary importance of peat swamp forest as a major habitat (Meijaard, 1997).

Peatland covers a vast area (ca. 6 million ha) of the lowlands of Kalimantan (Rieley et al., 1996). Only a very small proportion (<3%) of this habitat is protected within National Parks (MacKinnon and MacKinnon, 1991) and the area of undisturbed peat swamp forest is declining rapidly. Most of the forest on shallow, coastal peatlands, with peat thickness <3 m has been cleared and the land converted to agriculture, whilst all of the sub-coastal and interior peatlands with thick peat (>3 m) have been allocated for timber extraction through the Indonesian Ministry of Forestry logging concession system. In Central Kalimantan, between 1996 and 1998, 1 million ha of wetland (mostly peatland) were deforested and drained for agricultural production and settlement. This 'Mega-Rice Project' (Notohadiprawiro, 1998) was abandoned without growing crops and with the loss of a major area of orang-utan habitat.

Owing to the rapidly increasing rate of peat swamp forest degradation and loss, there is an urgent requirement to obtain more accurate estimates of current orang-utan numbers in this habitat. There are difficulties, however, in estimating population sizes of orang-utan owing to their natural low densities and semi-solitary nature (Galdikas, 1985). In the past, densities were estimated from intensive field surveys that relied on direct sighting methods. This work was carried out mostly in protected areas and densities were extrapolated to cover a wide range of unprotected habitats, resulting in over-estimates of population size (MacKinnon, 1992; Rijksen and Meijaard, 1999). Most

of the orang-utan habitat outside of formally protected areas remains unsurveyed although the recent development of non-encounter surveys, for example, estimating orang-utan densities from counts of their nests (arboreal sleeping platforms) along line transects, has the potential to change this (van Schaik et al., 1995a). Orang-utans make nests daily and individuals rarely re-use old nests (MacKinnon, 1971). Over a period of time old nests decompose and disappear. The nest-count method requires an accurate estimation of the time taken for nests to degrade. This variable is then used in the conversion of nest density to orang-utan density. An alternative method has also been employed whereby two surveys are performed and only nests that have appeared since the first survey are used to estimate density. In this instance the time taken for nests to degrade is not needed, although sample sizes must be large (Singleton, 2000). It has been found that orang-utan densities derived from nest counts compare favourably with the 'true' density (van Schaik et al., 1995a). Reasonably reliable estimates of the orang-utan population size of a large study area in Sumatra have been derived by combining densities with information on land use and vegetation cover obtained from satellite images (van Schaik et al., 1995b, 2001).

The investigation described in this paper was carried out in Central Kalimantan in an area of peat swamp forest that is currently the subject of other ecological and environmental studies (Rieley et al., 1997; Page et al., 1999). Several peat swamp forest sub-types have been identified within the study area, corresponding to peat of different thickness and hydrology. Parts of the study area have also been selectively logged over a 20-year period. The principal aims of our field research were to (1) estimate orang-utan population densities in the principal peat swamp forest vegetation sub-types using nest counts from line transect surveys; (2) investigate orang-utan densities in forest blocks subject to varying levels of disturbance from logging operations; (3) predict the population size of orang-utan in a larger peatland area, of which the field study area forms part, by combining density estimates with areas of the forest sub-types derived from satellite images.

2. Study area and methods

2.1. Study area

The study area is located in the Pt. Setia Alam Jaya timber concession, 20 km southwest of Palangkaraya, the Provincial capital of Central Kalimantan in the upper catchment of Sungai (Sg.) Sebangau which is part of a very large peat-covered landscape between Sg. Katingan to the west and Sg. Kahayan to the east (total area is approximately 9200 km², Fig. 1). Most of this

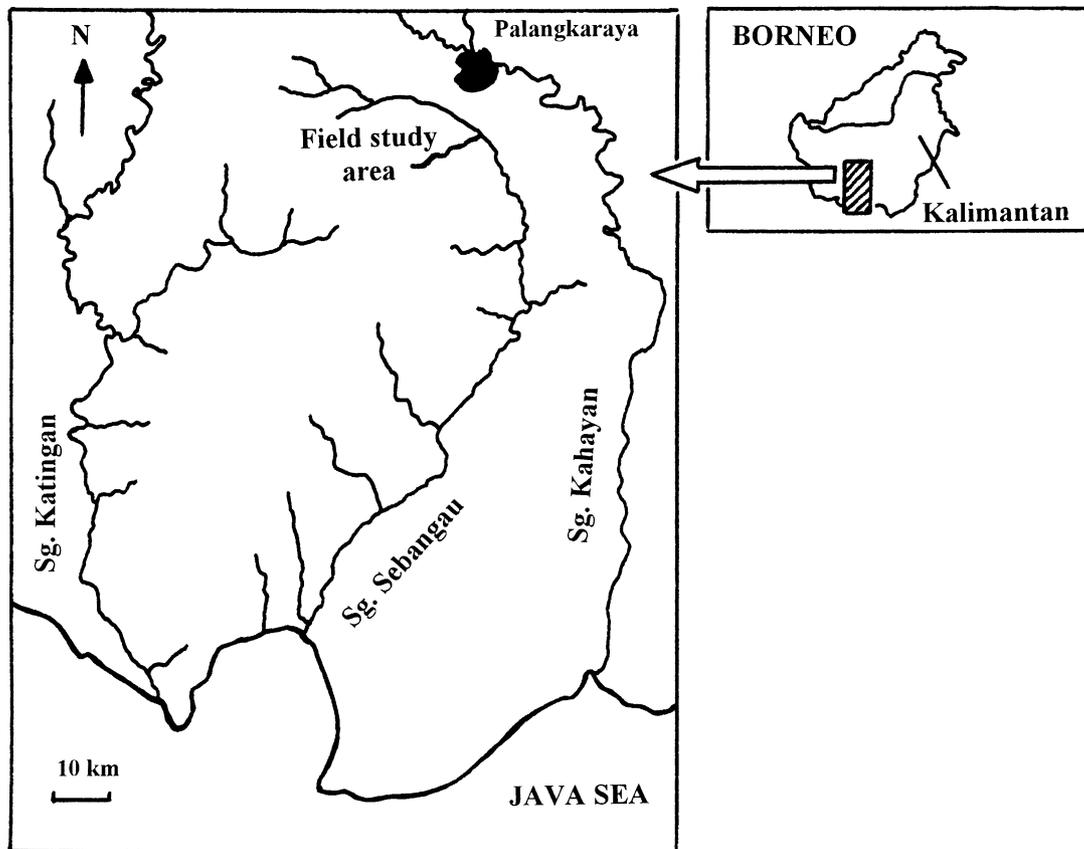


Fig. 1. The location of the Sungai Sebangau catchment in Central Kalimantan, showing the main field study area in the north of the catchment and the extent of the larger peat-covered landscape unit, between Sungai Katingan in the west and Sungai Kahayan in the east, of which the Sebangau catchment forms part.

area is covered with peat swamp forest although there has been some land development for agriculture and settlement, particularly near to Palangkaraya and on the Sg. Paduran in the southeast of the area. At the time of the field surveys the peatland forests were all allocated to logging concessions and timber extraction was taking place on a selective basis using semi-mechanized methods. Small-scale harvesting of non-timber forest products (bark, rattan and latex) was also taking place. Access to ca. 500 km² of primary peat swamp forest was obtained by using the timber extraction railway that ran southwest and then west from the logging company base camp, cutting across the peat-covered watershed between Sg. Sebangau and Sg. Bulan and passing through a range of forest sub-types on peat of varying thickness from 0.8 to 13 m (Fig. 2).

Three principal peat swamp forest sub-types have been described from the study area based on tree species composition and forest structure (Shepherd et al., 1997; Page et al., 1999). The zone beyond the limit of river flooding on the margins of the peat dome, up to a distance of 6 km from the river on peat up to 6 m thick is dominated by a mixed swamp forest. This forest canopy has three strata with a maximum height of 35 m. The principal tree species of the upper canopy are

Gonystylus bancanus [ramin (local name)], *Shorea* spp. (meranti), *Cratoxylon glaucum* (gerrongang) and *Dactylocladus stenostachys* (mentibu). Mixed swamp forest grades into low pole forest, which continues for a further 7 km or so. Low canopy forest has only two strata and very few trees of commercial value. The principal species of the upper canopy are *Combretocarpus rotundatus* (tumeh) and *Calophyllum* spp. (bintangor). Owing to the higher light levels penetrating the canopy, and the permanently high water table in this forest zone, there is dense undergrowth of *Pandanus* and *Freycinetia* spp. (pandans). The summit of this watershed (13–23 km from Sg. Sebangau) is occupied by forest with a much taller canopy consisting of four strata of trees with emergents up to 45 m. This ‘tall interior forest’, which grows on peat with a thickness of 10–13 m, contains a greater abundance of commercial tree species than the other forest types, including species of the genera *Agathis* (agathis), *Dactylocladus* (mentibu), *Gonystylus* (ramin), *Koompassia* (kempas), *Palaquium* (nyatoh) and *Shorea* (meranti) (Shepherd et al., 1997).

Records of mammal sightings made in this area in 1993 and 1994 confirmed the presence of orang-utan at an apparently high density (Page et al., 1997) in

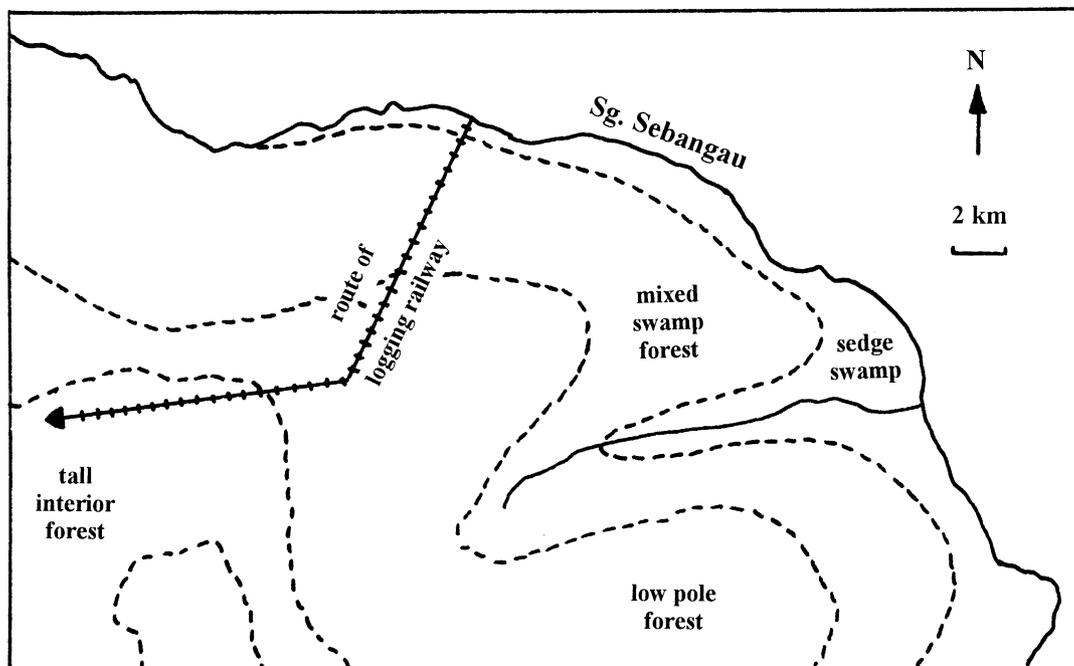


Fig. 2. Location of the timber extraction railway at the Setia Alam field study site in the upper catchment of Sungai Sebangau. The railway provided an access route to several peat swamp forest sub-types, the approximate boundaries of which are indicated (broken lines).

addition to several other endangered or threatened mammals, including agile gibbon (*Hylobates agilis*), maroon langur (*Presbytis rubicunda*), sun-bear (*Helarctos malayanus*), leopard cat (*Felis bangalensis*) and marbled cat (*F. marmorata*). Six red-data book bird species were also recorded (Page et al., 1997).

2.2. Field survey

Field surveys were carried out during August 1995 and August 1996. Orang-utan nests were counted by observers who walked slowly along line transects cut through the three principal forest sub-types (mixed swamp forest, low pole forest and tall interior forest) and a transitional forest between low pole and tall interior forest. The transects, which were a minimum distance apart of 1 km, commenced 100 m from, and ran perpendicular to, the main timber extraction railway. The starting point was chosen in a restricted random manner in order to ensure that all forest sub-types were sampled, with the exception of one transect, which had been pre-cut by logging workers. Each transect was intended to have a minimum length of 1 km but access constraints meant that this was not always possible, especially in low pole forest.

The perpendicular transect-to-nest distances (m) in the horizontal plane were estimated for every nest observed. The decay stage of nests was recorded in one of four classes: (1)=fresh, leaves still green; (2)=older, nest still in original shape, firm and solid, leaves still attached but brown; (3)=old, holes appearing in nest;

(4)=very old, twigs and branches still present, but no longer in original shape. The nature of forest disturbance to the mixed swamp forest was also recorded in two categories: 'recent', i.e. areas subject to timber extraction within the last 2 years and 'old', i.e. areas in which timber extraction had not taken place for at least 2 years (elsewhere surveys were conducted only in areas that had not been subject to recent disturbance). This classification was based upon the age of extraction routes and researchers' accounts during the 2 years prior to this survey. Since harvesting of non-timber products from the forest occurs at a uniformly low intensity throughout this was considered to have a negligible impact upon orang-utan distribution. Nest densities were estimated for each forest habitat sub-type and, in the case of mixed swamp forest, for areas of differing disturbance.

2.3. Data analysis

Orang-utan nest densities for each habitat type were calculated using the software programme DISTANCE 3.5 (Thomas et al., 1998). This automated technique uses distance-sampling data (in this case total transect length, number of nests observed and the perpendicular distance of each nest from the transect base line) to estimate density, and is reliable where transect lengths are known accurately (Cassey and McArdle, 1999). DISTANCE attempts to fit several possible models to the data in order to estimate the effective transect strip width, and selects the model with the best fit according

to the Akaike Information Criterion (AIC; Buckland et al., 1993).

Nest densities are converted to orang-utan densities using the relationship:

$$D = N/(p \times r \times t)$$

where D = orang-utan density, N = nest density, p = proportion of nest makers in the population, r = rate at which nests are produced (number per individual per day), t = time a nest remains visible (days).

2.3.1. Estimating the parameters

Knowledge of the parameters p , r and t is crucial to convert nest densities into accurate estimates of orang-utan densities. Since their values vary between populations and habitats, ideally they should be determined separately for each survey site. Direct measurement of these variables, however, requires intensive field research beyond the scope of the present survey. Therefore, the p and r values used in this study have been obtained from previous studies by other workers, whilst t values have been obtained both from published data and an indirect field method.

Rijksen (1978) suggests an r value of 1.8 for Ketambe, Sumatra while van Schaik et al. (1995a) provide estimates of 1.7 and 1.6 for the same site. The latter used a median value of 1.7. More recently, a study by Singleton (2000) at Suaq Balimbing, Sumatra, estimated an r value of 1.9. Comparable data does not exist for Kalimantan, so the first nest count surveys here used the median Sumatran figure of 1.7 (Yanuar et al., 1996; Russon et al., 2001). There appears, however, to be differences between the rates of nest production by the different orang-utan species. Galdikas (personal communication) proposes an approximate r value of 1.0–1.1 in Tanjung Puting National Park, Central Kalimantan; Knott (personal communication) reports a value of 1.1 in Gunung Palung National Park, West Kalimantan; and Lackman-Ancrenaz (unpublished memorandum) a figure of 0.9 in the Kinabatangan Wildlife Sanctuary, Sabah. These researchers indicate a very low frequency of day-nest construction within the Bornean species, and Lackman-Ancrenaz also reports a high rate of nest reutilization for both day and night nests that may be an adaptation to secondary forest habitat. The published range of values for r is 0.9–1.1 nests per individual per day for Borneo and 1.7–1.9 for Sumatra.

The Sumatran studies also indicate that ca. 10% of individuals in the populations studied were infants and young juveniles that did not make nests. This is not expected to differ significantly between Sumatran and Bornean populations, but is likely to be lower in areas where poaching or hunting is common, which is often the case when logging is taking place. Therefore p , the

proportion of nest-makers in the population, ranges from 0.9 to 1.0.

Duration of nest visibility t is the most likely parameter to vary between habitat types and survey sites, and studies of nests from construction to disappearance have produced a wide range of values. Rijksen (1978) estimated a median value for t of 81 days in lowland freshwater swamp forest at Ketambe, Sumatra and Djojosedharmo (cited in van Schaik et al., 1995a) proposed a mean value of 90 days. In contrast, Singleton (2000) suggested a mean value of 228 days for swamp forest and 319 days for low-hill forest at Suaq Balimbing, Sumatra. For Borneo, Lackman-Ancrenaz (unpublished memorandum) has estimated t to be approximately 250 days in Sabah, whilst a study using the Markov Chain method (details later) provided a value of 145 days in Danau Sentarum Wildlife Reserve, West Kalimantan (Russon et al., 2001). This gives a range of values for t of 145–250 days for Borneo and 81–319 days for Sumatra.

According to van Schaik et al. (1995a) three factors are involved in nest decomposition, namely rainfall, temperature and wood density. Peat swamp forest is botanically and structurally different from other types of lowland, tropical forest and its microclimatic conditions are also likely to vary. It is important, therefore, to calculate a value for orang-utan nest decay rate t that is relevant to the conditions prevailing within the particular study area, rather than using a value derived from studies in other forest types and other geographical locations. A technique was employed in this present study that relies on re-recording the decay stage of nests of known initial state of decay (van Schaik et al., 1995a). This enables estimation of the transition rates between decay stages that represent a stepwise Markov chain (Kemeny et al., 1956) with an absorbing state (nest gone). The expected number of steps to reach the absorbing state and the visibility duration of each nest were calculated. The fundamental matrix (N) of the Markov chain was determined by taking the transition matrix among the non-absorbing states Q (nest stages a through to d). The fundamental matrix N of this Markov Chain is then defined as:

$$N = (I - Q)^{-1}$$

where I is the identity matrix. The entries in N give the expected number of steps in each of the non-absorbing states from each possible non-absorbing starting state (i.e. the preceding nest stage class). Summing the number of steps for each decay stage to the next transition state indicates the total number of steps from stage a until absorption (nest disappearance).

During 1996, 86 nests were marked on the original survey and revisited after a period of 30 days. On the second survey the age of each nest was reassessed with

the additional nest age class ‘gone’ added. It was not possible to repeat this assessment in the low pole or tall interior forest sub-types owing to limitations on survey time.

3. Results

3.1. Estimating the time t during which a nest remains visible

Table 1 shows the figures for estimating the number of steps in each nest state. The total number of steps from nest stage ‘a’ until absorption (nest gone) is 9.47×30 , where 30 is the number of days between each census. This gives a degradation time of 284 days but this may be an overestimate of up to 30% (van Schaik et al., 1995a) as a result of an inherent bias in the method. Van Schaik et al. incorporated a correction factor of 0.7627 to take this into account but whether or not this high degree of correction is applicable in Borneo, where there is a lower incidence of day-nest construction, is questionable. It is true, however, that the degradation time varies from nest to nest, and the higher a nest’s t value, the more likely it is to be observed in a survey of nests (van Schaik et al., 1995a). We therefore provide two figures for t , an uncorrected estimate of 284 days and a corrected estimate of 217 days.

3.2. Estimating orang-utan densities

A total of 288 orang-utan nests were observed along 17.23 km of transects through peat swamp forest. Nest densities for each forest sub-type and, in the case of mixed swamp forest, for areas of different disturbance are shown in Table 2, along with the models chosen by DISTANCE to produce these estimates (Buckland et al, 1993; Thomas et al, 1998). The highest nest density was found in the old disturbed mixed swamp forest and the lowest in the recently disturbed mixed swamp forest. The estimate for mixed swamp forest is an average of recent and old disturbed areas, weighted by survey effort. Overall, the tall interior forest has the highest nest density by habitat sub-type, followed by the mixed swamp forest, transitional tall interior/low pole and low pole.

Inaccuracies in the parameters used to convert nest densities to orang-utan densities can lead to errors. Therefore, densities were estimated using different parameter values (Table 3). For r the mid-range value was weighted towards the data for Borneo, as the difference between Sumatran and Bornean populations appears to be consistent. For t the mid-range value used is 217 days, estimated in Section 3.1 using the correction factor, and the maximum value for Borneo is the uncorrected figure of 284 days. The maximum densities (columns 4 and 5, Table 3) are unfeasibly high for Borneo and can be ruled out. The low values for nest

Table 1
Estimating nest decay rate ($n = 86$; interval = 30 days)

Nest age class	Second survey				
	a	b	c	d	“gone”
<i>(a) Transition matrix for orang-utan nest ages in mixed swamp forest</i>					
First survey					
Stage a	0	10	1	0	0
Stage b	0	23	15	0	0
Stage c	0	0	13	10	1
Stage d	0	0	0	10	3
<i>(b) Transition probabilities matrix (Q)</i>					
First survey					
Stage a	0	0.91	0.09	0	0
Stage b	0	0.61	0.39	0	0
Stage c	0	0	0.54	0.42	0.04
Stage d	0	0	0	0.77	0.23
gone	0	0	0	0	0
<i>(c) The fundamental matrix N</i>					
	Nest state		Number of steps in each nest state		
	a			1.00	
	b			2.33	
	c			2.17	
	d			3.97	
	Total no. of steps			9.47	

Table 2

Orang-utan nest densities in four peat swamp forest sub-types in the Sungai Sebangau catchment, Central Kalimantan, with comparative estimates for mixed swamp forest with differing levels of human disturbance

Peat swamp forest sub-type	Transect length (km)	Number of nests	DISTANCE model selected	Nest density (number km ⁻² ± SE)
Mixed swamp	5.25	86	Uniform and cosine	599 (±78)
Low pole	2.30	15	Uniform and cosine	285 (±59)
Transitional				
low pole/tall interior	4.20	49	Uniform and cosine	355 (±45)
Tall interior	5.48	138	Hazard rate and cosine	636 (±133)
Total	17.23	288		
Mixed swamp—old disturbance	2.35	55	Uniform and simple polynomial	1040 (±202)
Mixed swamp—recent disturbance	2.90	31	Uniform and cosine	267 (±53)

Table 3

Orang-utan densities (*D*) calculated from the nest densities in Table 2 using a range of parameter values representing minimum and maximum figures reported from Borneo (columns 2 and 4); across the full range of *Pongo* spp. (columns 1 and 5) and a mid-range set of figures (column 3)

	Min <i>D</i>	Min <i>D</i> Borneo	Mid- <i>D</i>	Max <i>D</i> Borneo	Max <i>D</i>
parameter <i>p</i>	1.0	1.0	0.95	0.9	0.9
parameter <i>r</i>	1.9 ^a	1.1 ^b	1.2	0.9 ^c	0.9
parameter <i>t</i>	319 ^a	284	217	145 ^d	81 ^e
<i>Orang-utan density in each peat swamp forest sub-type (individuals km⁻² ± SE)</i>					
Mixed swamp	0.99 (±0.13)	1.92 (±0.25)	2.42 (±0.32)	5.10 (±0.66)	9.13 (±1.19)
Low pole	0.47 (±0.10)	0.91 (±0.19)	1.15 (±0.24)	2.43 (±0.50)	4.34 (±0.90)
Transitional low pole/tall interior	0.59 (±0.07)	1.14 (±0.14)	1.44 (±0.18)	3.02 (±0.38)	5.41 (±0.69)
Tall interior	1.05 (±0.22)	2.04 (±0.43)	2.57 (±0.54)	5.42 (±1.13)	9.69 (±2.03)
Mixed swamp—old disturbance	1.72 (±0.33)	3.33 (±0.65)	4.20 (±0.82)	8.85 (±1.72)	15.85 (±3.08)
Mixed swamp—recent disturbance	0.44 (±0.09)	0.85 (±0.17)	1.08 (±0.21)	2.27 (±0.45)	4.07 (±0.81)

^a Singleton (2000).

^b Galdikas (personal communication) and Knott (personal communication).

^c Lackman-Ancrenaz (unpublished memorandum).

^d Russon et al. (2001).

^e Rijksen (1978).

degradation, *t*, seem most unlikely. Likewise the high value for *r* used to estimate the minimum densities (column 1, Table 3) seems improbable for Borneo where studies from both northern and southern parts of the island provide similar values of 0.9–1.1. The actual density of orang-utans in the Greater Sg. Sebangau catchment is most likely to fall within or near to the range of values given as the minimum density for Borneo and the mid-range density (columns 2 and 3 highlighted in bold type, Table 3).

3.3. Estimating the population size within the Greater Sg. Sebangau catchment

In order to provide an estimate of the size of the orang-utan population of a much larger peat-covered landscape unit a 1991 LANDSAT TM remote sensed image covering the area between the Katingan and Kahayan Rivers was obtained. Most of this area of 9200 km² is peatland with extensive peat swamp forest still remaining (Fig. 1). This image had been used previously

to classify the principal land uses and vegetation types, including the peat swamp forest sub-types (Table 4).

Various adjustments were made to the field-derived estimates of orang-utan densities and to the land use and vegetation type categories before estimating the orang-utan population size within the total landscape unit. The 1900 km² of deforested land occupied by agricultural and urban areas were attributed a density of zero as these land uses do not provide suitable orang-utan habitat. It was also evident from the satellite image that an area of 1500 km² of mixed swamp forest between the Sebangau and Kahayan rivers had been heavily logged and it was assumed that this would support an orang-utan density similar to that determined for recently disturbed mixed swamp forest (Table 3).

Population size was estimated using each of the five sets of densities estimated in Section 3.2 (Table 5). In addition, corrections adopted at the 1993 Orang-utan PHVA Workshop have been applied to the total population sizes to prevent upwardly biased estimates (Rijksen et al., 1995). These authors suggested a correction

Table 4
Land use and vegetation cover of a large peat-covered landscape between the Katingan and Kahayan rivers in Central Kalimantan based on analysis of a 1991 LANDSAT-TM image

Land use and forest sub-types	Area (km ²)
<i>Peat swamp forest</i>	
Mixed swamp forest	3900
Low pole forest	2900
Transitional forest (low pole/tall interior)	100
Tall interior forest	400
Total area of peat swamp forest	7300
Agriculture and urban land (mostly on peat soils)	1900
Total	9200

factor of 0.6 to take into account over-estimation of densities across areas of poor-quality habitat, inaccurate mapping and logging disturbance. Other studies have used 0.75–0.80 where it is considered one or more of these factors are not relevant (van Schaik et al., 1995b, 2001; Russon et al., 2001). It could be argued that these reduction factors do not apply to our study as the surveys took place within identified habitat sub-types, within areas where the degree of logging disturbance was known and with the assistance of up-to-date satellite images. In order to ensure the total population size is not overestimated, however, correction values of 0.6 and 0.75 have been applied to our results (Table 5). The total population for the whole landscape unit is calculated to be within the range 2926 (± 499)–45,020 (± 7562) individuals. The true figure is considered most likely to fall within the range 5671 (± 955)–8951 (± 1509) individuals (Table 5, figures shown in bold type).

4. Discussion

4.1. Evaluation of the field survey and statistical methods

Nest count surveys provide the only feasible means of obtaining orang-utan density estimates in a short period of time and in relatively inaccessible and inhospitable habitats. The accuracy of this method, however, must

be questioned and its merits assessed. There are several potential sources of error that are discussed later.

4.1.1. Failure to meet line transect assumptions

Line transect sampling methods rely on four basic assumptions that must be met to ensure validity of results. They are: (1) objects are detected at their initial location, (2) all objects located exactly on (or above) the transect line are detected, (3) distances are measured accurately and (4) transects are located randomly in the habitat.

Assumption (1) is clearly fulfilled as nests do not move. It cannot be guaranteed that all nests directly on the transect were recorded, but special attention was paid to this and, as the peat swamp forest habitat is relatively unstratified with a generally low canopy, meeting assumption (2) is more likely in this habitat type than elsewhere. Examination of nest sighting histograms produced by DISTANCE did not provide evidence that nests were missed at zero distance. Field checking of perpendicular distances, and an absence of heaping of distance estimates at 5-m intervals (i.e. at 10, 15, 20 m from the transect, a common human error), suggests that assumption (3) is adequately met. Transects were located without bias towards habitat features or high-density areas. Trail location within flat, homogeneous peat swamp forest is probably of less importance than it would be in areas of rugged terrain. It was impossible to bias surveys consciously towards high-density areas as there was only one access route into the forest and surveyors had no prior knowledge of the area. Thus, assumption (4) is adequately met. Seasonal variations in density are probable but the direction of potential bias is, as yet, unknown.

4.1.2. Minimum transect length required

Both van Schaik et al. (1995a) and Singleton (2000) found that transect lengths of 1.5–1.9 km were suitable, although these were for high density areas in Sumatra and longer transect lengths may be required for lower density areas such as Borneo. In this study, graphs plotting the cumulative number of nests to distance surveyed levels out suggesting that the total transect distances sampled in each habitat sub-type were sufficiently long.

Table 5
Estimates of orang-utan population size (\pm standard error) in a large peat-covered landscape between the Katingan and Kahayan rivers, Central Kalimantan, calculated by extrapolating the range of density estimates in Table 3 to the area occupied by suitable orang-utan habitat in Table 4. The most likely upper and lower limits appear in bold type

	Min <i>D</i>	Min <i>D</i> Borneo	Mid <i>D</i>	Max <i>D</i> Borneo	Max <i>D</i>
Uncorrected estimates	4878 (± 832)	9452 (± 1592)	11,935 (± 2013)	25,162 (± 4199)	45,020 (± 7562)
Correction Fig. 0.75	3658 (± 624)	7089 (± 1194)	8951 (± 1509)	18,871 (± 3149)	33,765 (± 5671)
Correction Fig. 0.60	2926 (± 499)	5671 (± 955)	7161 (± 1207)	15,097 (± 2519)	27,012 (± 4537)

4.1.3. Estimation of the parameters p , r and t

Ideally these should be estimated for each site separately, but if these are not known the range of values found elsewhere must be considered. These parameters may not only differ between sites, but also within a site. The value estimated for t in this study is at the top end of the range of published values, although the reason for this is not known. Botanical differences between peat swamp forest and other forest types may contribute to the longer nest degradation time.

4.1.4. Nest sighting probability

All nests at a given distance from the transect should have an equal probability of being seen during the survey. This is unlikely to be the case, however, as the height, age and size of each nest will affect its sighting probability. As pointed out by Singleton (2000) there is likely to be a real distance over which the line of sight is least obstructed by foliage. Very high and very low nests may be obscured by intervening vegetation. Large nests are more likely to be seen than small nests. Likewise, old nests at an advanced stage of decay (and to a lesser extent new, green nests) are less likely to be seen compared to intact b class nests, even though old nests are included equally in estimations of the degradation time t .

It appears that the errors discussed above lead generally to underestimates of density. Van Schaik et al. (1995a) found that nest-count surveys had underestimated densities at Ketambe by ca. 10–15%, whilst Singleton (2000) underestimated densities at Suaq Balimbing by up to 80% using the all nest single survey method. The most striking means by which overestimates of population size are produced is through the extrapolation of densities over a large area, and care must be taken with this.

4.2. Orang-utan densities and population size

Mixed swamp and tall interior forest sub-types are the preferred orang-utan habitats within the study area and these appear to support most of the population. These forest sub-types also have a larger forest biomass per unit area than low pole forest. The tall interior forest has the largest trees and basal area per unit area of all of the sub-types, whilst low pole forest has the smallest (Shepherd et al., 1997; Page et al., 1999). The differences in orang-utan densities between the forest sub-types may, therefore, be related to differences in forest structure and productivity. The abundance of trees producing soft pulp fruits could be of importance as this has been shown to correlate positively with orang-utan abundance (Djojosedharmo and van Schaik, 1992). Low pole forest could play an important role as an ‘overflow’ habitat for sub-adult males or as a corridor habitat from the mixed swamp forest to the tall interior

forest. It is of interest that several males, but no females, were sighted in low pole forest. Males are not as reliant on high food abundance and quality as females, which are usually accompanied by infants. In addition, males are more mobile and both their home and day ranges are larger than those of female orang-utan, enabling them to exploit sub-optimal habitats during seasonal periods of higher fruit production. Females have stable ranges and will not leave their home range even when important food resources are available nearby (Galdikas, 1988; Rodman, 1988; van Schaik and van Hooft, 1996).

This study, in common with several others, shows that orang-utan densities decrease following disturbance caused by logging activities (e.g. MacKinnon, 1971; Rijksen, 1978; Davies and Payne, 1982; van Schaik et al., 1995a; Russon et al., 2001). When orang-utan are exposed to human disturbance they move out of the local area but may return again once the disturbance is over (MacKinnon, 1971) except that if the disturbance is throughout a female’s home range she will not be able to escape the disturbance (Singleton, personal communication). Densities in the old disturbed area of the mixed swamp forest, where logging had not taken place for at least 2 years, were four times as high as in areas of recent logging activity. High densities in previously logged areas have been reported elsewhere and attributed to displacement of orang-utans (Rijksen and Meijaard, 1999; Russon et al., 2001). This may result in what has been termed ‘refugee crowding’ (Rijksen and Meijaard, 1999), which leads to an overshoot of the carrying capacity of the habitat. Timber extraction also provides increased opportunities for poaching (MacKinnon, 1986; Sugardjito and van Schaik, 1992).

In this study, the estimates of orang-utan density for a large peat-covered landscape unit compare favourably with other published values for Borneo. High densities of 2–4 individuals km^{-2} have been reported for lowland dipterocarp, freshwater swamp forest and mixed freshwater/peat swamp forest, whereas hill dipterocarp forest supports lower densities of around 0.3–0.5 individuals km^{-2} (Payne and Andau, 1989; Sugardjito and van Schaik, 1992; Russon et al., 2001). Mean densities for the Sumatran orang-utan in the Gunung Leuser National Park, where habitat quality is exceptionally good, are of the order of 3–5 individuals km^{-2} (Rijksen, 1978; van Schaik et al., 1995a, 2001).

Whilst it is clearly difficult to estimate the total orang-utan population size for the Greater Sg. Sebangau catchment with absolute accuracy, such extrapolation is crucial to determine the importance of this area for orang-utan. Through consideration of all the potential errors in the method and the application of correction factors to the population predictions, we estimate that the number of orang-utan inhabiting the peat swamp

forests between the Katingan and Kahayan rivers during 1996 was between 5671 (± 955) and 8951 (± 1509) individuals (columns 2 and 3, Table 5). This is substantially above 2000 individuals, the minimum population threshold that Sugardjito and van Schaik (1992) suggest is necessary for a population to be self-sustaining. Yeager (1999), however, in an analysis incorporating the greater levels of environmental stochasticity witnessed in recent years (including fire and drought), suggests that even populations as large as 2000 individuals may not be sustainable. The estimate of the population size of the Bornean orang-utan published by Rijksen et al. (1995) did not take into account the population inhabiting the Greater Sg. Sebangau catchment. If the minimum and maximum population figures from our study are added to those of Rijksen and his co-workers, then a more accurate estimate of the total Bornean population may lie in the range 15,953–24,497, with possibly 37% of this population living in the Greater Sg. Sebangau catchment of Central Kalimantan. This population estimate needs to be confirmed by further detailed survey in other parts of this vast area, although both orang-utans and their nests have been observed in many locations in the northern Sebangau catchment (personal observation).

4.3. *The future of orang-utan in peat swamp forest*

This study emphasises the contemporary importance of peat swamp forest habitats for the conservation of orang-utan. In Central Kalimantan the huge majority of the remaining peat swamp forests are designated as production forest or conversion forest, but illegal logging and deforestation are currently reducing the forested area. Forest fire also presents a major threat. Recent experience of the El Niño event in 1997 has shown that large areas of peat swamp forest can be destroyed, especially when damaged by excessive logging and drained by canal construction.

This study suggests that the Greater Sg. Sebangau area supports the largest single orang-utan population remaining in Borneo. Indeed, if the true figure approaches the maximum population estimate of 8951 (± 1509) individuals it may be the largest contiguous wild population in existence. Previously ignored by the scientific community, the Greater Sg. Sebangau is the last intact, extensive forest habitat of the southern race of the Bornean orang-utan and it should be protected. It is recommended that (1) plans to convert further areas to agriculture are abandoned and prevented from happening in the future, (2) effective law enforcement to prevent illegal logging and hunting of orang-utan is implemented, and (3) steps are taken to reverse the damaging effects of the drainage canals constructed during the failed mega-rice project and for extraction of

illegally logged timber. Ultimately, as one of only a few areas of Borneo considered to hold a sustainable population of over 2000 individuals, the Greater Sg. Sebangau area needs to be designated as a National Park for the conservation of orang-utan. In addition to the Sebangau catchment, large areas of orang-utan-inhabited peat swamp forest also occur between the Kahayan and Kapuas Rivers, between the Katingan and Mentaya Rivers, and between the Kapuas and Barito Rivers, in Central Kalimantan. These areas are also critical for the future of this primate in Borneo and should also be considered for some form of wildlife protection status. Habitat protection is urgently required otherwise the Kalimantan orang-utan population, which is already at a critically low level, will face extinction within a relatively short period of time (Rijksen and Meijaard, 1999).

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